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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,411,683,** on November 13, 2002, by **LUXELL TECHNOLOGIES INC.,** assignee of Richard P. Wood and David J. Johnson, for "OLED with Contrast Enhancement Features".

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ABSTRACT

An organic electroluminescent device is provided having emitting layers with materials and thicknesses that provide constructive optical interference of emitted light. The device includes additional layers that provide contrast enhancement through destructive optical interference of ambient light entering the device.

OLED with Contrast Enhancement Features

Field of the Invention

The present invention relates to electroluminescent devices, and more particularly relates to contrast enhancement filters that are applied to electroluminescent devices.

Background of the Invention

Known contrast enhancement filters include optical interference filters as described in US5049780 to Dobrowolski and US6411019 to Hofstra, the contents of which are incorporated herein by reference. In certain teachings of Dobrowolski and Hofstra contrast enhancement is provided by an optical interference member that is placed in front of a reflective rear electrode or reflective rear cathode. As more particularly described therein, reflections of ambient light off of the rear electrode or rear cathode are used in conjunction with the optical interference member to create at least two, out-of-phase, wave forms of ambient light, which interfere with each other to cause at least some cancellation of each other and thereby reduce unwanted reflections of ambient light from the display.

Other known contrast enhancement filters include light absorbing materials that coat the reflective electrode or cathode. See, for example, WO 00/25028 to Berger et al, which contemplates the use of a graphite to coat a reflective rear cathode. These purely absorbing materials then reduce reflections of ambient light that enter the front of the display, by effectively converting that ambient light into heat.

However, these prior art structures may not be suitable where it is desired to actually utilize the reflectivity of the rear cathode in order to boost the amount of light emitted from the device. Put in other words, while the above-mentioned prior art devices reduce

ambient light that reaches the rear cathode of the display, the prior art devices also tend to reduce the light that is backwardly *emitted* towards the rear of the display. Indeed, in certain prior art OLED displays it is known to select an appropriate emitting region portion of the light emitting layer, to cooperate with the reflective electrode, in order to achieve a total phase shift of rearwardly emitted light of about 360°, and thus the two light waves will constructively interfere enhancing the brightness of the device.

Presuming an ideal reflector and that the two light waves are thus equal in magnitude when they interfere, the intensity will be:

$Irf=(Ef+Er)^2$
$Ef=Er=E$
$Irf=4E^2$

Where Ef=electrical field of the forward emitted light and Er= electrical field of the rear emitted light, and Irf is the intensity seen by the viewer using a reflective rear electrode.

If Er is absorbed, as is the case with a dark electrode, the equation become simply:

$Idk=(Ef+Er)^2$
$Ef=E, Er=0$
$Idk=E^2$

And Idk is the intensity seen by the viewer using a dark rear electrode. Thus Idk/Irf=1/4=0.25 and the device using the dark rear electrode is only 25% as efficient as the device using the reflective rear electrode.

While it is known to reduce ambient light reflections in the above-described display using a circular polarizer applied to the front of the display, the circular polarizer also has the additional effect of absorbing some of the emitted light, in some devices typically about

56 to about 62%, and in such devices the reflective rear electrode device is about 38% to about 44% efficient.

Summary of the Invention:

It is therefore an object of the present invention to provide an display with contrast enhancement feature that mitigates or obviates at least one of the above-identified disadvantages of the prior art.

In an aspect of the present invention, there is provided a electroluminescent display that embeds the light emitting layers within the optical interference structure itself.

Brief Description of the Drawings

Certain preferred embodiments of the present invention will now be explained, by way of example, with reference to the attached Figures in which:

Figure 1 shows a side sectional view of a bottom emission organic electroluminescent device in accordance with an embodiment of the invention; and,

Figure 2 shows a side sectional view of a top emission organic electroluminescent device in accordance with another embodiment of the invention;

Detailed Description of the Invention

Referring now to Figure 1, a semi-reflecting thin film BL1 is in front of the light emitting layers (identified in Figure 1 as Organic 1, Organic 2), while a reflective layer BL2 is located behind the light emitting layers. The light emitting layers serve as material that is nominally transparent to ambient light entering the device, and which causes a phase shift of the that ambient light, as will be discussed in greater detail below.

Semi-reflecting film BL1 serves two purposes:

1. It breaks the incoming light into two pieces, a reflected ray and a transmitted ray; and
2. It phase shifts the light reflected from it by about 180° relative to the light reflected from the rear electrode. Note that approximately 10-15% of the light is reflected back towards the viewer.

However, in order to achieve the destructive interference which leads to the device having low reflectance and thus appearing black, the total relative phase shift provided by the organic layers located between the semi-reflecting and reflecting thin films should be about 0°. Note that as the light is reflected the total phase shifts occurs as the light travels two times through the organic layers: once as it is entering the structure and once upon reflection.

In this embodiment, the destructive interference of ambient light can be achieved while maintaining the constructive interference conditions that can occur in a device utilizing a reflective cathode. In this embodiment the total thicknesses of the organic layers leads to about 0° phase shift for light traveling through them, reflecting off of the rear cathode and traveling back out of the device, relative to the light reflected from the semi-reflecting layer in front. However, the constructive interference conditions can also be maintained between the forward and rear emitted light by independently controlling the distance between the emitting region and the reflective rear electrode.

Note that light reflected from the first layer will be reflected from both the front interface and the rear interface. It is the resulting sum of these two light rays that have the about 180° phase shift, and thus the thickness of this layer is chosen accordingly to achieve this effect.

In order to achieve a 10-15% reflectance value from this light array the material will generally have some degree of absorption associated with it, typically reflected in an optical absorption constant k, whereas the optical density is defined by the index of

refraction, n. The combination of n, k and thickness is chosen to achieve both the phase shift and the desired degree of reflection.

The combination of the absorption constant k, and the thickness of this film will lead to light also being absorbed into this film. This will lead to some of the emitted light being absorbed as it exits the device.

The location of semi-reflective layer BL1 can occur at various places within the device as long the it is located between the viewer and the light emitting layers Organic 1 and Organic 2, and the total internal phase shift is about 0° relative to the light reflected from this first semi-reflective layer. For example there is typically a layer of a transparent conductive material within a device which served to conduct current to the device as well as provide a means for the emitted light to escape the device and reach the viewer, typically Indium Tin Oxide.

In variations of the present embodiment semi-reflective layer BL1 can be located between the viewer and the ITO, or the ITO can be located between the semi-reflective layer BL1 and the viewer. Particularly in the latter case, the thickness of the ITO is not particularly limited (though it may be selected in relation to desired electrical operation, such as to accord with the operating voltage of the device). In the first case the thickness of the ITO is taken into account to achieve the relative phase shift of about 0°.

Note that if the first semi-reflective layer BL1 is in contact with the organic layer of the device will also be selected to have an appropriate work function. However, a work-function matching layer can also be inserted between the semi-reflecting layer and the organic layers. Regardless, the first reflective layer will also be at least partially conductive according to the electrical operation requirements of the device.

The organic layers will typically consist of a hole injection layer and an electron injection layer. (The location of these layers depend on whether the device is a "bottom emission device" (Figure 1) in which the anode is located closest to the viewer, or a "top emission

device" (Figure 2) in which the cathode is located closest to the viewer.) In either case, in SMOLED devices, the light emitting region is located within 50-200 Å of the interface of these two layers. For constructive interference of the emitted light to occur, the location of this interface relative to the reflective rear electrode is carefully considered. For destructive interference to occur the total thickness of these layers is also carefully considered. The various distances can be controlled as well by inserting layers of conductive organic material, typically CuPc, next to either the rear or front electrodes.

After the organic layer(s) there is a reflective layer. Note that this can consists of either a single layer of metal, for example Aluminum, or a thin film device of several layers, such as that described in the prior art which can be tuned to a particular level of reflectance. In the simplest device most light is reflected and back to interfere with the light reflected from the first semi-reflecting layer. In another embodiment the reflectivity of a thin film device of several layers can be tuned to ensure that the amplitude of the light reflected from this region is similar to the amplitude of the light reflected from the first semi-reflective layer, noting that some of the light will be absorbed as it passes through the also semi-absorbing, semi-reflective layer.

In this embodiment also the light reflected from these rear layers can also be phase shifted to enhance the light cancellation, which can add a certain degree of freedom to the phase shifting requirements of the other layers, ie. the organic stack and first semi-reflective layer.

In another embodiment specifically relating to the top emitting structure, the first semi-reflective layer can act as the electrode, eliminating the need for a transparent conducting material, such as ITO. It can also act as a buffer layer to protect underlying organic materials from damaging processes.

If the semi-reflecting layer is located in the device in such a manner so as to be conducting electricity, it is likely that layer will have to be patterned into the shape of the electrode it is in contact with. However, in another embodiment this layer may be

electrically isolated from the structure through the use of an insulating layer. In a top emission structure this would mean depositing an insulator on top of the front electrode and then depositing the semi-reflective layer. The thickness of the insulating layer would then have to be taken into account in the phase shift of the transmitted light. In a BE device the semi-reflective layer would have to be deposited onto the substrate along with an insulating layer to isolate it from the front transparent electrode. Again the thickness of the insulating layer would then have to be taken into account in the phase shift of the transmitted light. The advantage is that the semi-reflective layer would no longer have to be patterned and the OI effect could occur between pixels as well as on the pixels themselves.

In another embodiment, if the first semi-reflective layer is itself an insulator the insulating layers can now be removed.

Exemplary embodiments are shown in Figures 1 and 2.

This are summarized as follows:

Bottom Emission Device (Figure 1):

Substrate (Glass, Plastic)/ ITO/ CuPC / BL1/ TPD/AlQ3/BL2/Al

ITO: Typical thickness is about 1200 Å, but within a range of about 1000 to about 5000 Å.

CuPC: Typical thickness is about 250 Å, but within a range of about 0 to about 300 Å. The combined thicknesses of these two layers should be about 1450 Å to give a 180 degree phase shift on a single pass (assuming standard n, k values).

BL1: Material can be Aluminum Silicon Monoxide. By altering the aluminum content, the conductivity, reflectivity, work function and absorption can be altered. A typical film

of 2 parts aluminum and 3 parts silicon monoxide would give optical constants of n~ 3.1, k~0.3, and a thickness of about 443 Å but within a range of about 300 to about 600 Å.

TPD or Organic 1, about 400 Å

AlQ3 or Organic 2, about 500 Å

Note that the sum of the thicknesses of these two materials are preferably about 1300 Å to allow for a 360 degree phase shift on two passes (assuming standard n, k values) of emitted light. A buffer layer, eg CuPc, may be used to reduce the thicknesses of these two layers.

BL2: A wide range of materials may be used. Aluminum Silicon Monoxide can be used. The ratio of aluminum to silicon monoxide must be altered to provide the desired reflectance values. In an optimal device this layer is omitted to get maximum reflection from the rear cathode.

Al: 1200 Å

Top Emission Device (Figure 2):

ITO/ CuPC / BL1/ TPD/AlQ3/BL2/Al / Substrate (Glass, Plastic)

ITO: Typical thickness is about 1200 Å but within a range of about 1000 to about 5000 Å being acceptable.
CuPC: Typical thickness is about 250 Å, with a range of about 0 to about 300 Å. The combined thicknesses of these two layers should be about 1450 Å to give a 180 degree phase shift on a single pass (assuming standard n, k values).

BL1: Material can be Aluminum Silicon Monoxide. By altering the aluminum content, the conductivity, reflectivity, work function and absorption can be altered. A typical film

of 2 parts aluminum and 3 parts silicon monoxide would give optical constants of n~ 3.1, k~0.3, and a thickness of about 443 Å but within with a range of about 300 Å to about 600 Å.

TPD, having a thickness of about 400 Å

AIQ3, having a thickness of about 500 Å

Note that the sum of the thicknesses of these two materials need to be approximately 1300 Å to allow for a 360 degree phase shift on two passes (assuming standard n, k values). A buffer layer, eg CuPc, may be used to reduce the thicknesses of these two layers.

BL2: A wide range of materials may be used. Aluminum Silicon Monoxide can be used. The ratio of aluminum to silicon monoxide is chosen to provide the desired reflectance values. In an optimal device this layer is omitted to get maximum reflection from the rear cathode.

Al: having a thickness of about 1200 Å

ITO can be used as BL1 when the optical constants are tailored to meet the desired requirements of a semi-reflecting layer. Aluminum or silver doped ITO is known to increase absorption (conductivity increases as a by-product). In this case, the ITO is about 450 Å thick, plus any additional thicknesses of about 1450 Å. A typical thickness would then be about 1900 Å.

Presently preferred performance of both of these embodiments is about 0% reflectance at about 555 nm of visible light, and about 45 to about 50% efficiency as compared to the ideal case of a tuned reflective cathode device without a circular polarizer.

We claim:

1. An electroluminescent device comprising:

a Substrate
an ITO layer deposited behind said substrate;
a CuPC layer deposited behind said ITO layer;
a semi-absorbing layer deposited behind said CuPC layer
a TPD layer deposited behind said semi-absorbing layer;
an AlQ3 layer deposited behind said TPD layer;
a reflective layer deposited behind said Alq3 Layer;
an Al cathode deposited behind said reflective layer
wherein said semi-absorbing layer thickness and material is chosen to cause at least some destructive optical interference of ambient light entering through said substrate;
wherein said TPD and Alq3 layers have a thickness chosen to cause at least some constructive optical interference of ambient light that is emitted from some at least one of saidTPD and Alq3 layers;
and wherein said TPD and Alq3 layers also have a thickness that cooperates with said semi-absorbing layer and said reflective layer to cause at least some further destructive optical interference of ambient light entering through said substrate.

The above-described embodiments of the invention are intended to be examples of the present invention and alterations and modifications may be effected thereto, by those of skill in the art, without departing from the scope of the invention which is defined solely by the claims appended hereto.

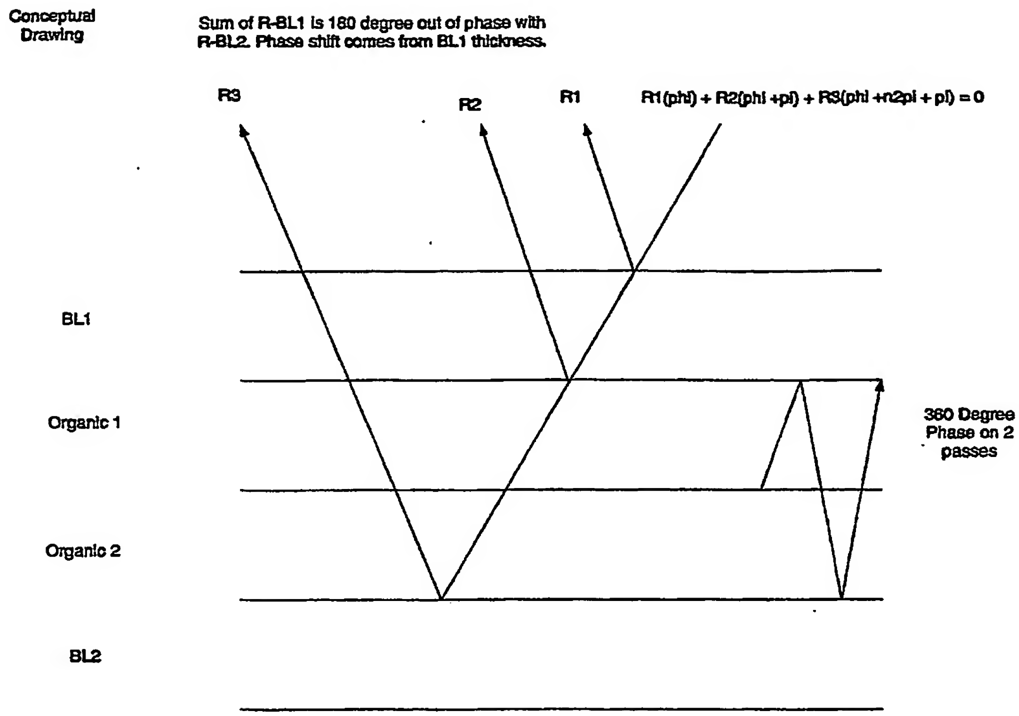
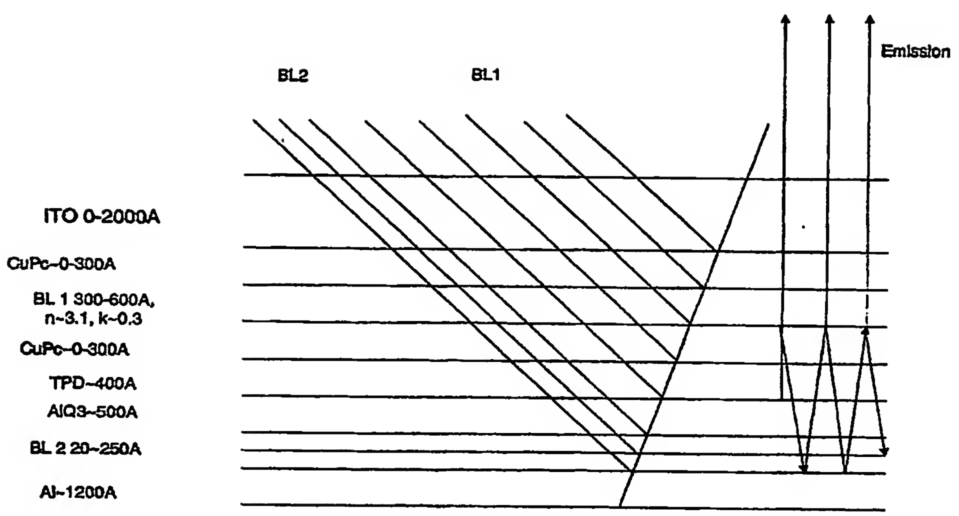

Conceptual Drawing
Sum of R-BL1 is 180 degree out of phase with R-BL2. Phase shift comes from BL1 thickness.
R3
R2
R1
R1(phi) + R2(phi +pi) + R3(phi +n2pi + pi) = 0
BL1
Organic 1
Organic 2
BL2
360 Degree Phase on 2 passes

Fig. 1

A) Top Emission-
Configuration 1



The crucial point is that destructive and constructive components are decoupled. The optical path of BL 1 provides the 180 degree phase shift. Where the sum of BL1 components cancels with BL2 components

Constructive interference is maintained between BL1 and BL2 when phase separation is 360 degrees on 2 passes.

CuPC layers for enhanced optical tuning and work function matching

ITO can be removed, with BL1 as common anode.

Fig. 2